

## TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	<b>DECLARATION</b>	<b>ii-iii</b>
	<b>DEDICATION</b>	<b>iv</b>
	<b>ACKNOWLEDGEMENTS</b>	<b>v</b>
	<b>ABSTRACT</b>	<b>vi</b>
	<b>ABSTRAK</b>	<b>vii</b>
	<b>TABLE OF CONTENTS</b>	<b>viii-xi</b>
	<b>LIST OF TABLES</b>	<b>xii</b>
	<b>LIST OF FIGURES</b>	<b>xiii-xvi</b>
	<b>LIST OF ABBREVIATIONS</b>	<b>xvii</b>
	<b>LIST OF SYMBOLS</b>	<b>xviii-xix</b>
1	INTRODUCTION	
	1.1 Introduction	1
	1.2 Objectives of the Study	2
	1.3 Scope of the Present Study	3
	1.4 Significance	3
2	MUON SCIENCE AND THE MUSIC PROJECT AT OSAKA UNIVERSITY	
	2.1 What are muons?	5
	2.2 Overview of the MUSIC project	6
	2.3 Physics Programs at the MUSIC project	7

2.3.1	Elementary Particle Physics	8
2.3.2	Materials Science	8
2.3.3	Muon catalyzed fusion	8
2.4	Hardware Components of the MUSIC project	9
2.4.1	Pion Capture System	10
2.4.2	Muon Transport System	11
2.4.3	Phase Rotation System	12
2.5	Beam Specification of the MUSIC Project	13

### 3 DEVELOPMENT OF NEW BEAM DETECTOR FOR MUSIC

3.1	Requirement of a beam detector for MUSIC	16
3.1.1	Position Measurements	16
3.2	Particle Detector for the MUSIC	17
3.2.1	Design Overview	17
3.2.2	Plastic Scintillating Counter with WLS-Fiber embedded	19
3.2.3	Wavelength Shifting (WLS) Fibers	20
3.2.4	Multi-Pixel Photon Counter (MPPC)	22
3.2.5	Trigger Counters – Photomultiplier Tube (PMT)	28
3.2.6	Beta source – Strontium 90	29
3.3	Principle of Hit position Measurements	31
3.3.1	Energy deposit (Bethe-Bloch Equation)	32
3.3.2	Solid angle Estimation	35
3.3.3	Timing Information	37
3.3.4	Light yield estimation	37
3.4	Estimation of Position Resolutions	38

4	OVERVIEW OF THE EXPERIMENT SETUP	
4.1	Overview of Equipments	39
4.2	Instruments	40
4.2.1	Voltage Divider	40
4.2.2	MPPC Circuit	41
4.2.3	Collimator	42
4.3	Readout Electronics	42
4.3.1	Signal Conditioning Unit	42
4.3.2	Coincidence Logic	43
4.4	Data Acquisition System (DAQ)	44
4.5	Data Taking System at PC	45
5	MEASUREMENTS WITH RADIOACTIVE SOURCES	
5.1	Performance of MPPC	46
5.2	Measurement with one MPPC	47
5.2.1	Logic Circuit	47
5.3	Measurement with two MPPCs	49
5.3.1	Logic Circuit	49
5.4	Measurement with 12 MPPCs	50
5.4.1	Logic Circuit	50
6	TRIGGER USING PHOTOMULTIPLIER TUBE	
6.1	Photomultiplier Tube noise Check	51
6.2	Measurement using two Photomultiplier Tube	53
6.3	Measurement using different scintillator Conditions	54
6.3.1	Mirror	55
6.3.2	Open	56
6.3.3	Black Sheet	56
7	RESULTS AND DISCUSSION	
7.1	Measurement with radioactive source	58
7.2	Trigger using Photo Multiplier Tube	64

8	CONCLUSION AND FUTURE PROSPECTS	
8.1	Conclusion	70
8.2	Future Prospect	72
	REFERENCES	73-74
	APPENDICES – DESCRIPTION OF ELECTRONICS	
A.1	Amplifier	
A.2	Discriminator	
A.3	Analog to Digital Converter	
A.4	Gate Generator	
A.5	Fan in/ Fan Out	

## LIST OF TABLES

<b>Table No.</b>	<b>Title</b>	<b>Pages</b>
6.1	Rate of events for both conditions	52
6.2	Rate for both PMT and their coincidence	53
7.1	Channel per photons for each MPPCs.	60
7.2	Resolution for detector with different scintillator condition.	68

## LIST OF FIGURES

<b>Figure No.</b>	<b>Title</b>	<b>Pages</b>
2.1	Layout of MUSIC project in RCNP Osaka University	7
2.2	Muon Catalyzed fusion cycle	9
2.3	Solenoid magnet (red) for the Pion Capture System connected to a Muon Transport System	10
2.4	PRISM-Fixed Field Alternating Gradient Ring (FFAG)	13
2.5	Artificial production intensity	14
2.6	(a) Graph of momentum mean versus magnetic field.	14
	(b) Graph of muon yields versus magnetic field	14
2.7	Muon beam profile	15
3.1	Plastic Scintillator stripped with WLS-fi.	17
3.2	Support Connector (Aluminum)	18
3.3	Support Connector (Plastic)	18
3.4	(a) Side view of the connectors.	19
	(b) Upside view of the connectors.	19

3.5	WLS fiber stripped into plastic scintillator.	19
3.6	Inner structure of Wavelength Shifting fiber	20
3.7	(a) MPPC with $1\text{mm}^2$ active area.	22
	(b) MPPC consist of multiple APD	22
	(c) 100pixel ceramic MPPC.	22
3.8	Basic operation process in MPPC	23
3.9	Graph number of fired pixels versus number of generated photons.	24
3.10	Signal of MPPC taken with (a) oscilloscope (b) ADC	25
3.11	Graph of Gain versus bias voltage.	26
3.12	Graph of noise rate versus voltage difference.	27
3.13	Graph of crosstalk rate versus voltage difference.	27
3.14	Graph of Strontium-90 deposit energy	29
3.15	Number of photon detected by MPPC	32
3.16	The Bethe-Bloch equations solved for numerous materials	34
3.17	Fiber is divided into smaller element	36
3.18	Particle passage into WLS-Fiber.	36
4.1	Overall view of hit position detector.	40
4.2	Voltage Divider	41
4.3	Simple MPPC circuit.	41
4.4	Beta particle collimator	42
4.5	Signal conditioning Unit consists of amplifier and Discriminator	43

4.6	Coincidence Logic	43
4.7	Data Acquisition System (DAQ)	44
5.1	Experimental setup to check MPPC performance.	47
5.2	Signal of MPPC taken with (a) oscilloscope (b) ADC	47
5.3	Measurement of one MPPC	48
5.4	ADC signal observed on oscilloscope	48
5.5	2 MPPC connected to AND logic	49
5.6	Coincidence signal for 2 MPPC	49
5.7	Coincidence Logic for 12 MPPCs	50
6.1	PMT with cap set up	52
6.2	Plastic Scintillator attached to PMT	52
6.3	PMT 2 signal at high voltage = 1700V	54
6.4	Experimental setup for mirror condition	55
6.5	Experimental setup for open condition	56
6.6	Experimental setup for black sheet condition	57
7.1	Measurement with 12 MPPCs (Threshold: 5 photons)	60
7.2	ADC Histogram for MPPC without source.	61
7.3	ADC Histogram for MPPC near source.	62
7.4	ADC Histogram for MPPC far from source.	62
7.5	Number of photons signal on MPPC 1L and 1R	63
7.7	Light yield by each MPPCs.	63
7.8	Graph of calculated position versus real source position (Open Condition)	65



7.9	Graph of calculated position versus real source position (Aluminium Condition)	65
7.10	Graph of calculated position versus real source position (Black Sheet Condition)	66
7.10	Comparison between three scintillator conditions	67
7.11	Graph of Resolution versus source position (Open Condition)	68
7.12	Graph of Resolution versus source position (Aluminum Condition)	68
7.13	Graph of Resolution versus source position (Black Sheet Condition)	69
7.14	Comparison of Resolution versus source position for three scintillator conditions.	69

## LIST OF ABBREVIATIONS

MUSIC	MUon Science Innovative Channel
MPPC	Multi Pixel Photon Counter
WLS	Wavelength Shifting
PMT	Photomultiplier Tube
PDE	Photon Detection Efficiency
PRISM	Phase Rotated Intense Slow Muon Source
FFAG	Fixed Field Alternating Gradient Ring
LIDAR	Light Detection and Ranging
OTDR	Optical Time Domain Reflectometry
DAQ	Data Acquisition System
PC	Personal Computer
ADC	Analog to Digital Converter

## LIST OF SYMBOLS

$Q$	Magnitude of Charge
$C$	Capacitance
$V$	Operating Voltage
$V_{bd}$	Breakdown voltage
$M_s$	Center of Mass
$m$	Integer
$N_m$	Number of Photon at m
$N_L$	Number of Photon at left MPPC
$N_R$	Number of Photon at right MPPC
$x$	Instantaneous length
$L$	Fiber length
$\frac{dE}{dx}$	Rate of energy loss of particle with respect to distance
$\gamma$	Constant
$\beta$	Constant
$v$	Muons velocity
$c$	Speed of light
$Z$	Atomic number
$A$	Atomic mass
$I$	Mean excitation energy
$\delta$	Correction constant
$M$	Rest mass
$T$	Solid angle
$n_1$	Refractive Index 1

$n_2$	Refractive Index 2
$C$	Particle passage
$N_{\text{calc}}$	Number of calculated Photon
$N_{\text{scint}}$	Number of Photon first detected by scintillator
$P_{\text{fiber}}$	Probability of attenuation in fiber
$P_{\text{att}}$	Probability of attenuation in scintillator